Restoration of Barrier Islands Overlying Poorly-Consolidated Sediments, South-Central Louisiana

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ABSTRACT

Late Holocene barrier islands along south-central Louisiana comprise primarily very fine sand overlying poorly-consolidated, organic-rich, fine silts and clays. These barriers experience high rates of relative sea level rise largely due to subsidence. Lowering of a barrier island by subsidence is compounded as barrier sand is transported onto previously non-loaded sediments, *e.g.*, into the bay via overwash during storms or alongshore due to sediment transport. The existing barrier elevation and width may thereby be reduced, making future overwash and inlet breaching more likely, and the new deposit begins to load the previously poorly-consolidated substrate. Over century to millennial time scales, these barriers may become subaqueous and abandoned on the inner shelf (*e.g.*, Ship, Tiger, and Trinity shoals, Louisiana).

One means of abating barrier island loss is large-scale island restoration through infusion of sediment. Because barrier islands can protect fragile wetlands, infrastructure, and mainland shores, large-scale island restoration is being considered as part of the Louisiana Coastal Area Study. However, for those barriers overlying poorly-consolidated sediments, the additional loading due to island restoration will increase the magnitude and rate of local subsidence. Present design procedure does not account for time-dependent consolidation due to loading by initial placement of sediment on these islands and possible future maintenance renourishment. A newly-developed two-dimensional (cross-shore) mathematical model was applied to investigate the dependence of beach nourishment on barrier island morphologic change within a poorly-consolidated setting. Initial results indicate that, to minimize barrier island migration and maintain dune height, it is advantageous to construct one large nourishment project, rather than smaller projects that are renourished incrementally.

INTRODUCTION

Over the past five thousand years, deposition by the Mississippi River alluvial system in the Northern Gulf of Mexico has created a thick layer of fine silts, clays, and organics that forms the shoreface. Deltas are reworked by marine processes, winnowing fine sediment and forming spits and barrier island systems from sands and silts.

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Loading of the substrate by recently-deposited and reworked sediment results in additional loading, and the underlying sediment becomes compacted ("consolidates" in engineering parlance) through time (Fig. 1). Barrier islands eventually overwash during storms, creating washover fans, breaches, and inlets, thus losing their capacity to protect estuaries and bays, as well as reducing subaerial land with ecological benefits. Inlets that remain open capture a larger tidal prism as subsidence continues and sea level rises, thereby increasing currents and sediment transport adjacent to the remaining barrier islands.

Under the Louisiana Coastal Area Study (U.S. Army Corps of Engineers District, New Orleans, 2004) and in the post-Katrina Hurricane protection efforts (Fischetti, 2005), large-scale barrier island restoration is being considered as the "offshore shield" to provide reduction in wave forcing and storm surge on the mainland. However, large-scale restoration in this setting is different than for traditional beach nourishment projects: a much larger volume of sediment will be placed to provide protection, time-dependent consolidation of the underlying substrate must be factored into the design, and goals for the restoration may differ from traditional beach nourishment projects, *e.g.*, some overwash and inundation might be acceptable in the offshore shield approach. How should these large-scale restoration projects be designed and implemented? Is it more beneficial to place a large volume of sediment at one time to restore the barriers, which will incur a large consolidation and provide the best storm protection, or are smaller volumes placed incrementally more advantageous, to allow for occasional washovers and incur less consolidation?

In this paper, the first step in addressing these questions has been accomplished as proof-of-concept. A cross-shore (two-dimensional) model of barrier island migration, overwash, and consolidation is applied to the restoration problem. The paper first presents the theory behind the model, discusses model calibration and validation, and compares predictions for a large-scale restoration versus traditional incremental placement.

CONCEPTUAL MODEL OF BARRIER EVOLUTION

Previous studies of Atlantic barrier islands have investigated long-term morphologic change, which can be compiled into a general model for sandy barrier island migration (Table 1). It is instructive to discuss the sandy barrier island model and contrast how migration and processes for Louisiana barrier islands differ. The cycle of sandy barrier island morphologic change can be idealized to begin through the development of washover deposits and formation of flood shoals, both which are formed through erosion of sediment from the ocean side of the barrier system and deposited in the bay (as a flood shoal) or on the bayshore (in the form of a washover deposit) (*e.g*., Fischer, 1961; Kraft, 1971; Leatherman, 1979). Future overwash events can breach the barrier and create new inlets and flood shoals, and old inlets may close through longshore transport processes, leaving abandoned flood shoals in the bay. Abandoned ebb shoals may weld to the ocean beach or remain offshore as relic features. With time, additional overwash events transport sediment from the ocean side to create new washover fans that may overlap older deposits. Through this process, a shallow bayside "platform," onto which the barrier can migrate, is created. The bayside platform becomes vegetated, and shallow wetlands are formed. Eolian transport builds dunes on top of the new deposits. The rate of relative sea-level rise is sufficiently small that dunes can increase in elevation to maintain a viable barrier system as migration occurs. Over long time spans, the center of mass of the barrier island translates as these processes work to reshape it. A veneer of sand is abandoned on the shelf as the barrier migrates and forms inlets, and some of this sediment may be transported back towards the beach (Niedoroda *et al*., 1985).

This paradigm of barrier island migration differs somewhat for Louisiana. The mixed sediment system, limited sediment supply, influence of cold fronts in geologic change, rapid relative sea-level rise, and poorly-consolidated substrate modify the general model discussed above. Cold fronts are significant in altering barrier island morphology because (1) they occur frequently, with an average of 20 to 30 storms per year (Georgiou *et al*., 2005); (2) barrier islands are low (at most 2 m above sea level [Stone *et al*., 1997]), and are readily overtopped; and (3) waves and surge rework and redistribute sediment on the Gulf shore as the storms approach Louisiana, and on the bayside beach and wetlands after they make landfall. In discussion of physical processes for the Louisiana coast, Georgiou *et al*. (2005, p. 88) concluded "subsidence and the combined impact of occasional tropical cyclones and frequent cold fronts are largely responsible for coastal change."

Differences in the sandy island migration model presented above and processes in Louisiana are discussed here (second column of Table 1). First, depositional processes on the bayside of the barrier are similar to those experienced in sandy barrier island systems. However, the bayshore of the barrier island (composed of sand,

Main Menu
Search
Author Index
Papers
Help

Table 1. Conceptual models of barrier island migration processes and associated morphologic change.

Sandy barrier island system	Mixed sediment system; barrier overlies poorly-consolidated sediment
1. Bayside Deposition - Overwash and inlet processes create bay-side deposition - Overwash fans - Flood shoals - Bayside platform develops - Dunes reduce in height - Oceanside beach erosion	1a. Bayside Deposition - Similar as for sandy barrier 1b. Bayside Erosion - After storm passes barrier, winds on bays create waves that erode and scarp bayside beach; sediment is removed from active barrier littoral system
2. Longshore Transport Processes - Old inlets close through longshore transport processes, and new inlets are opened; abandoned ebb shoals weld to the beach	2. Longshore Transport Processes - Minimal sand supply in littoral system reduces likelihood that inlets will mend and close; spacing between barrier systems is wide, and inlets large; small breaches that formed during storms can remain, becoming wider through time; islands can translate laterally (or elongate, if anchored at updrift end)
3. Vegetation - Wetlands form on overwash fans - Dunes are vegetated, increasing accretive capacity	3. Vegetation - Similar, if enough time between overwash events for vegetation to grow
4. Eolian transport - Dunes are rebuilt through wind-blown transport - Dune elevation can maintain pace with relative sea level rise	4. Eolian transport - Typical wind speeds are insufficient to transport sediment, except prior to storms - Barrier islands are not wide enough to allow sufficient drying of sands, so that sand can readily be transported by winds - Dunes cannot rebuild to elevations to maintain pace with relative sea level rise
5. Nearshore deposits - Some sand is left on shelf as barrier migrates - A portion of abandoned ebb shoals remain as offshore sand sources - Some sand may transport back to littoral system	5. Nearshore deposits - Inlets with established ebb shoals are increasing in tidal prism due to larger bay areas; thus, ebb shoals are jetted further offshore and do not weld to the beach

clay, silt, and marsh) is eroded as storms pass due to waves that are generated on the bay. The bayshore sediment is transported into the bay, and removed from the active barrier island littoral system. Second, the lack of sand in the barrier island system and the increasing bay area combine in a trend such that established inlets rarely close (Levin, 1993); new breaches formed during storms may grow into permanent inlets, thereby fragmenting the barrier system. Third, vegetation of the dune and bayshore may occur if the time between overwash events is of sufficient duration. Fourth, eolian transport does not occur as regularly as for Atlantic coast barrier systems. On the northern Gulf of Mexico, eolian transport primarily occurs as part of the storm sequence (Stone *et al*., 2004). Typical wind speed is weaker than that required to transport sand, and barrier islands are not sufficiently wide to allow sand to dry and be readily transported by winds. Finally, ebb shoals do not bypass sediment or weld to the barriers as they can for Atlantic coast barriers. In Louisiana, relative sea-level rise is high, which has increased the bay area and tidal prism of the inlets (Georgiou *et al*., 2005). Thus, ebb shoals are jetted further offshore or drowned rather than bypassing sand or welding to the adjacent barriers.

Campbell (2005) discussed a four-stage conceptual model controlling barrier island retreat in Louisiana. This model begins with an initial barrier with a thin sand layer over mixed deltaic sediment (sand, silt, and clay), backed by a wide marsh system. During storms, the sand is eroded, and marsh vegetation and deltaic sediment are exposed to wave attack. Sand-sized sediment is released to the system as the beach retreats. Some of the sand removed from the barrier island during the storm eventually returns to the beach; however, the marsh is much reduced in area (Campbell, 2005). Although not explicitly stated, it is assumed that this model represents a storm passage followed by a recovery sequence, and the discussed processes probably occur over a time period of months to years. However, other processes are significant forces in determining the long-term morphologic change of barrier island systems in Louisiana.

For time scales covering storm-recovery cycles to decades and centuries, other acting processes include: overwash, development of washover fans, breaching, inlet formation, bayside beach erosion, revegetation of washover deposits, eolian transport, dune rebuilding, longshore sediment transport, and long-term consolidation of underlying sediment. An alternate conceptual model is proposed for Louisiana barrier island morphologic change and migration, as shown in Figure 2. This model begins with a barrier island configuration similar to that of Campbell (2005) (Fig. 2A); however, during the storm sequence (Fig. 2B), overwash fans develop and breaches may form. If the gulfside beach is removed, wetland vegetation and more erosion-resistant “core” sediments (Stone *et al*., 1997) are exposed to wave attack. As the storm moves landward, waves generated in the bay erode the bayshore and wetlands (Fig. 2C). These processes occur over time scales of days, and the barrier system may have migrated landward and alongshore, as well as become fragmented during the storm sequence. Recovery of the island occurs to a limited extent over months to years, and some revegetation and eolian dune building may take place (Fig. 2D). Over decades to centuries (Fig. 2E), consolidation of the underlying sediment increases the rate of relative sea-level rise, resulting in an increase in tidal volume captured by the bay and inlet tidal prism (Georgiou *et al*., 2005). Barrier island drowning occurs, and repeated storm sequences continue to rework the barrier sediment as shown in Figures 2B-2D.

This discussion has illustrated the differences in barrier island migration and morphologic change processes for Louisiana as compared to sandy barrier island systems overlying a sandy substrate. To summarize, for modeling long-term (decades to centuries) evolution, including the impacts of large-scale restoration projects with beach nourishment, the following processes must be taken into account: erosion of Gulf and bayside sand, vegetation, and core sediments; overwash and washover deposits; breaching; partial recovery of sand on the Gulf beach; eolian transport; vegetation of dunes and wetlands; longshore sediment transport; eustatic sea-level rise; subsidence due to geologic faulting and subsurface fluid withdrawal; and consolidation of poorly-consolidated sediment.

TWO-DIMENSIONAL (CROSS-SHORE) MODEL

As proof of concept, a two-dimensional (cross-shore) Migration, Consolidation, and Overwash (MCO) model has been developed to predict barrier island morphology change over periods of decades to centuries. The model calculates barrier migration and dune crest lowering caused by storm-induced overwash and compaction due to new loading of the substrate. Future versions of the model will incorporate erosion of the bayshore during the storm passage, eolian transport, dune-building, vegetation, and inlet breaching (Kraus and Hayashi, 2005).

The model simplifies the barrier island with a triangular shape that conserves mass through time (Fig. 3). The ocean-most point of the triangular barrier island remains pinned in place as the island migrates, thus simulat-

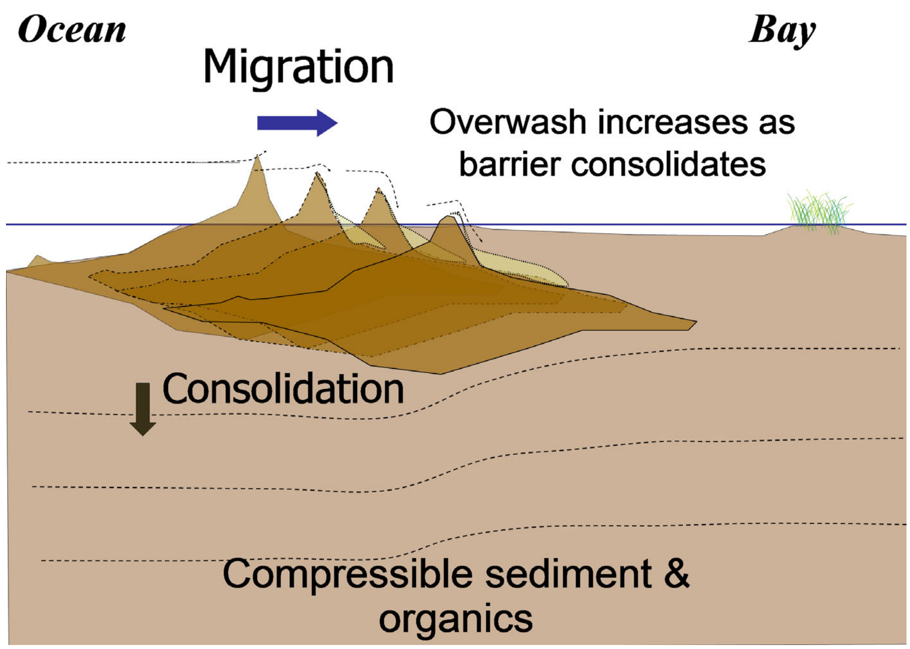


Figure 1. Consequences of consolidation on barrier island migration and overwash.

ing cross-shore losses as the barrier migrates landward. The barrier dune height, $b_h(t)$, varies due to the migration and spreading of the barrier in the cross-shore, as well as erosion of the dune due to washover. Storm surge plus astronomical tide $S(t)$ and zeroth-moment deep water wave height $H_{mo}(t)$ are randomly generated about a user-defined mean. The associated peak wave period, $T_p(t)$, is calculated by applying a relationship given by Bretschneider (1966), which has been modified for peak wave period:

$$T_p(t)(\text{sec}) = 2.53\sqrt{H_{mo}(t)(ft)} \quad \text{(1)}$$

The two-percent runup, $R_u(t)$, is calculated as (Hughes 2004):

$$R_u(t) = 4.4S(t)[\tan\beta(t)]^{0.70}\left[\frac{M_F}{\rho g S(t)^2}\right]^{1/2} \qquad for\ \frac{1}{30} \le \tan\beta(t) \le \frac{1}{5} \quad \text{(2A)}$$

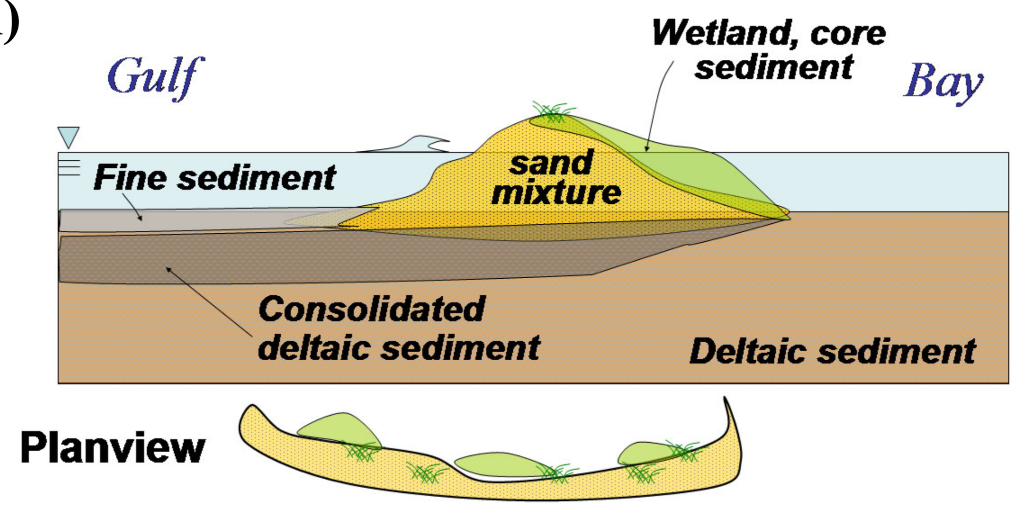
in which tan $b(t)$ is the beach slope, r is the density of water, and the maximum dimensionless depth-integrated wave momentum flux per unit width is:

$$\left[\frac{M_F}{\rho g S(t)^2}\right]_{\max} = A_0(t)\left[\frac{S(t)}{gT_p^2(t)}\right]^{-A_1(t)}$$

$$where \quad A_0(t) = 0.6392\left(\frac{H_{mo}(t)}{S(t)}\right)^{2.0256}$$

$$and \quad A_1(t) = 0.1804\left(\frac{H_{mo}(t)}{S(t)}\right)^{-0.391} \quad \text{(2B-D)}$$

(A)



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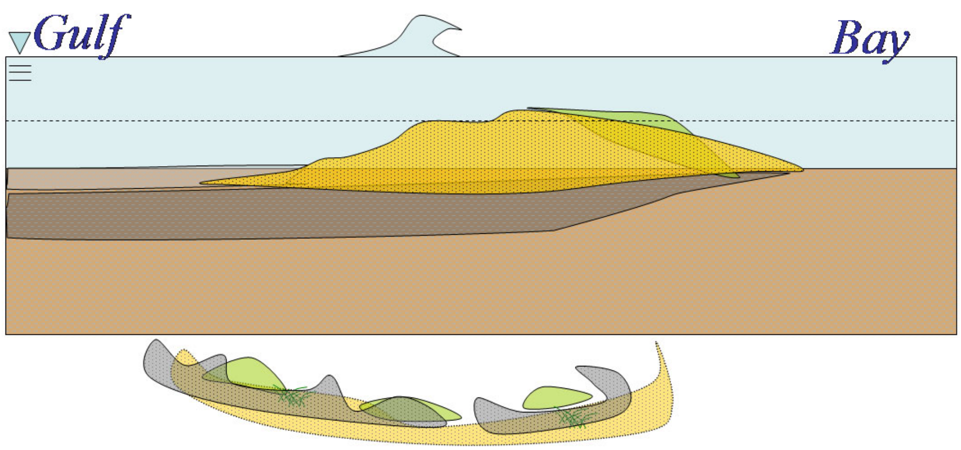

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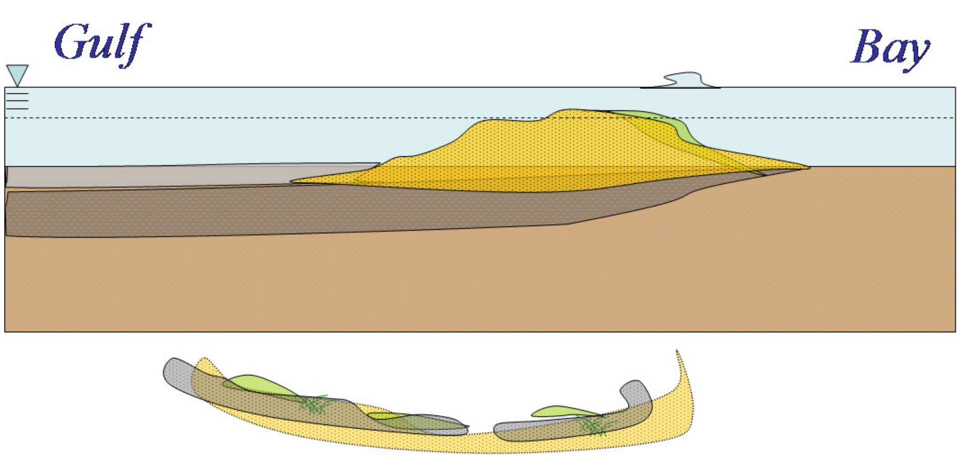

Main Menu
Search
Author Index
Papers
Help

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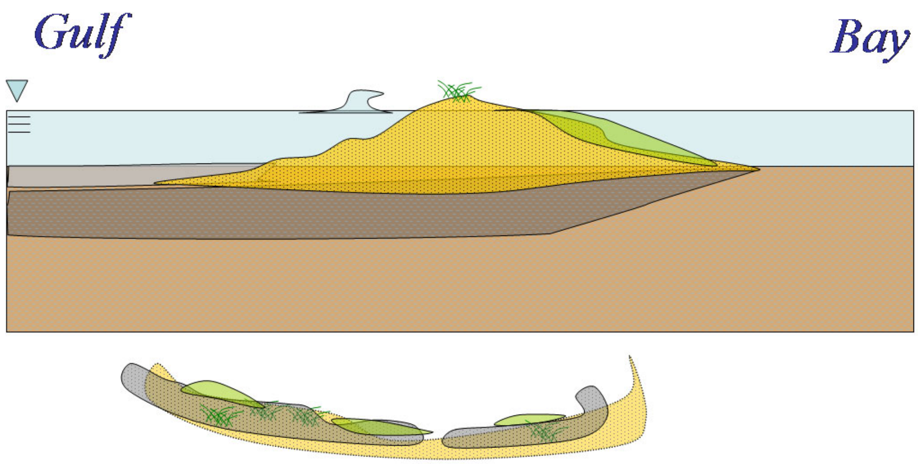

(E)

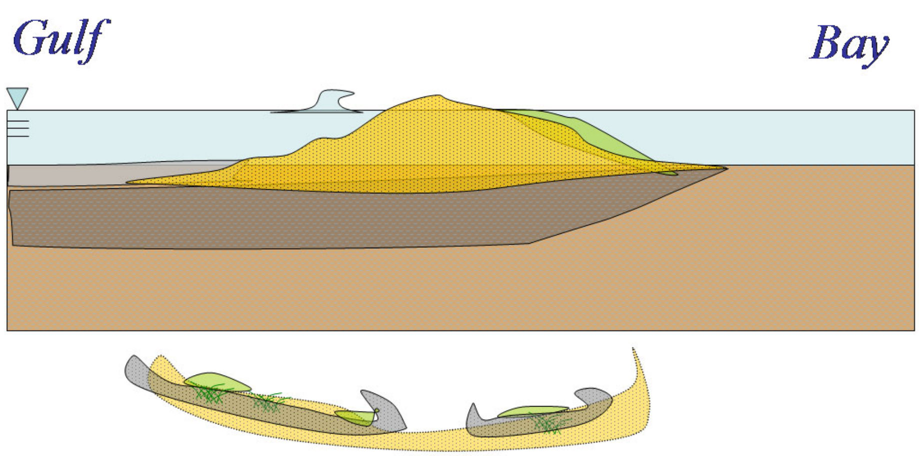

Figure 2. Proposed conceptual model for long-term barrier island migration and morphologic change in the northern Gulf of Mexico:

A. Pre-storm barrier island configuration;
B. Barrier island evolution during storm; time scale – days;
C. Storm waves from bay; time scale – days;
D. Post-storm partial recovery; time scale – months to years; and,
E. Long-term subsidence and eustatic sea level rise; time scale – decades to centuries.

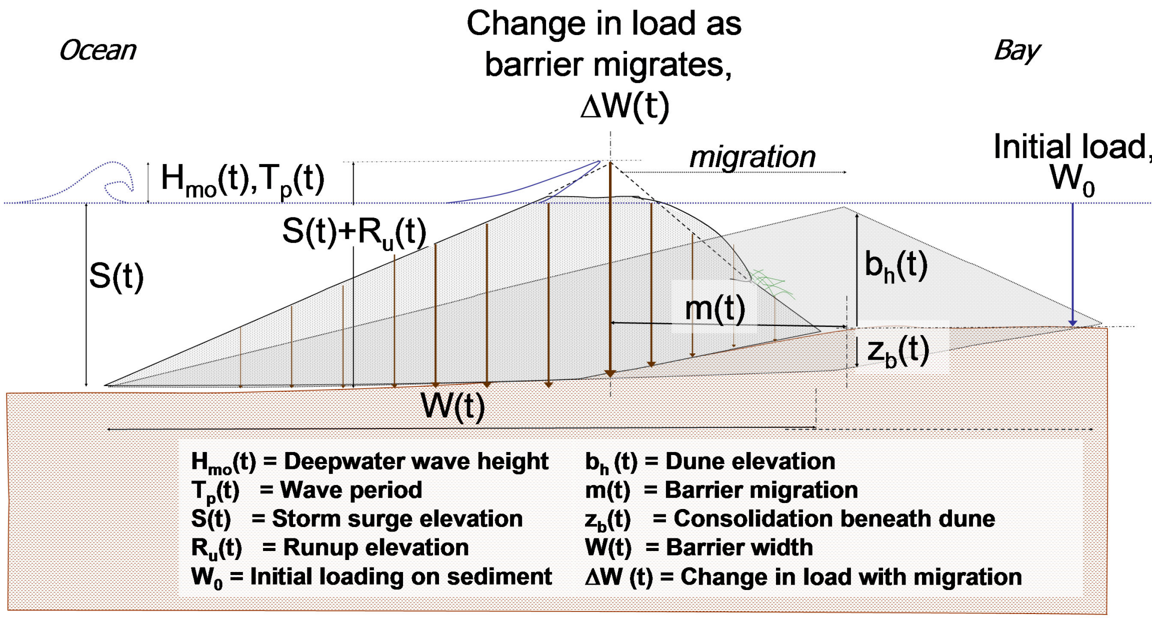

Figure 3. Definition of terminology for Migration, Consolidation, and Overwash model.

The volume of sand washed over the top of the barrier by runup, called the washover deposit (Leatherman, 1980), is calculated using one of two equations depending on whether the storm surge exceeds the crest of the barrier. For "runup overwash," in which the storm-surge elevation is less than the barrier height but the runup exceeds the barrier elevation, the overwash transport rate per unit length of beach, $q_{DR}(t)$ can be described as (Donnelly *et al*., in press):

$$q_{DR}(t) = 2K_R\sqrt{2g}\,\frac{z_R(t)^2}{R_u(t)}, \quad 0 < z_R(t) \text{ and } S(t) < b_h(t) \quad \text{(3A)}$$

where K_R is a calibration coefficient that accounts for sediment stirring and properties of the wave bore, set to 0.005; g is the acceleration due to gravity; $z_R(t)$ is the elevation of the runup minus the dune crest elevation. If the surge elevation exceeds the height of the barrier island, then "inundation overwash" occurs, and the transport rate over the beach crest per unit width of beach, q_{DI}, is given by (Donnelly *et al*., in press):

$$q_{DI}(t) = (K_I + K_R)\, 2\sqrt{2g}\; z_R(t)^{3/2}, \quad 0 < z_R(t) \text{ and } S(t) \geq b_h(t) \quad \text{(3B)}$$

in which K_I is an empirical coefficient set to 0.001, and other variables are as defined previously. Barrier migration, $m(t)$, is determined from the washover volume using Equation 3, geometry of the barrier, and conservation of total barrier volume.

Terzaghi (1943) derived a relationship for primary consolidation based on fundamental hydraulic principles. The assumptions for one-dimensional consolidation theory are: (1) a fully-saturated sediment system; (2) unidirectional flow of water; (3) one-dimensional compression occurring in the opposite direction of flow; (4) a linear relationship between the change in sediment volume and the applied pressure (linear small-strain theory); and (5) validity of Darcy's Law, which states that the specific discharge (flow rate per area) through a porous medium is equal to the hydraulic gradient times the hydraulic conductivity (Yong and Warkentin, 1966; Hornberger *et al*., 1998). For one-dimensional vertical flow, the final consolidation, z_c, for a given increase in loading, D_W, can be calculated as:

$$z_c = z_0\left(\frac{C_c}{1+e_0}\log_{10}\frac{W_0+\Delta W}{W_0}\right) \quad \text{(4)}$$

Main Menu
Search
Author Index
Papers
Help

where z_0 is the initial thickness of compressible sediment; C_c is the compression index, which is determined experimentally from a consolidation test; e_0 is the initial void ratio, equal to the volume of voids divided by the volume of solids, and averaged over z_0; and W_0 is the initial loading on the sediment (Fig. 4). In a study of the consolidation potential for Louisiana sediment, Kuecher (1994) found values of C_c equal to 4.7 to 5 for peat and organic muck; 1 to 3 for prodelta mud; 0.86 for bay sediment; 0.123 for natural levee sands and silts, and 0.063 for point bar sands. Larger C_c values indicate a greater potential for consolidation. Time-dependent consolidation of underlying sediment, $z_b(t)$, is calculated beneath the barrier dune using Terzaghi's (1943) time-dependent relationship for consolidation:

$$\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial z^2} \quad \text{(5)}$$

where u is the pore water pressure in excess of hydrostatic pressure, c_v is a property of the compressible sediment, called the coefficient of consolidation, and z is the vertical coordinate with the origin at the initial sediment surface (Fig. 4). The proportion of the initial pore water pressure remaining at any time, $M(t)$, can be expressed as:

$$M(t) = \frac{1}{z_0}\int_0^{z_0} \frac{u}{u_0} dz = \frac{e(t) - e_f}{e_0 - e_f} \quad \text{(6)}$$

in which u_0 is the initial pore water pressure, $e(t)$ is the average void ratio at any time, and e_f is the final average void ratio. The variable $M(t)$ varies between 1 and 0, at time t equals 0 and infinity, respectively. The vertical consolidation that occurs at any time can also be expressed as:

$$z_b(t) = z_c\left(\frac{e_0 - e(t)}{e_0 - e_f}\right) \quad \text{(7)}$$

Combining Equations 5 and 6 gives:

$$z_b(t) = z_c(1 - M(t)) \quad \text{(8)}$$

where $M(t)$ can be can be determined by using a form similar to a solution given by Dean (2002, p. 119) for the evolution of beach nourishment:

$$M(t) = 8\sum_{n=1}^{\infty} \frac{e^{-[(2n-1)\pi]^2 c_v t / 4 z_0^2}}{(2n-1)^2 \pi^2} \quad \text{(9)}$$

As the barrier migrates, the magnitude of consolidation under the dune at the new location is reduced to the value that occurred due to the previous (lighter) loading at that location. Consolidation may contribute significantly for subsiding barrier island systems that provide significant reduction of incident wave energy to mainland beaches and wetlands, such as in Louisiana (Stone and McBride, 1998).

MODEL VALIDATION

In a study of Virginia barrier islands, Gayes (1983) surveyed the barrier cross-shore profile and took sediment cores across three consolidating barrier island systems, Assawoman, Metompkin, and Wallops Islands. Based on the measurements and island migration rates, and accounting for eustatic sea level rise, these barrier island systems have experienced consolidation between 0.3 and 11.5 ft over 35 to 40 years.

Validation of the MCO model was conducted by applying Equations 7 and 8 to 28 data points from Gayes (1983). In his study, Gayes calculated the coefficient of consolidation representative of most data from labora-

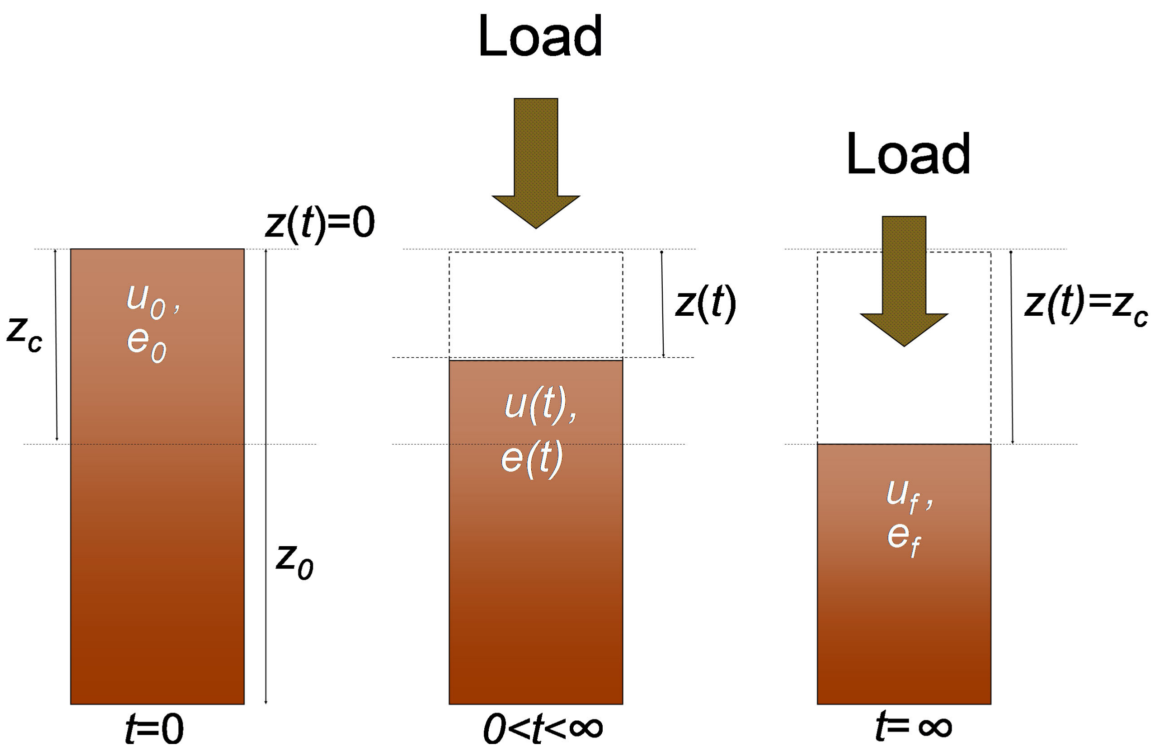

Figure 4. Definition sketch for consolidation relationship.

tory testing of core sediment, equal to c_v = 26.9 ft^2/yr. In this application, the sediment core with the largest consolidation value at each site was used to determine the value of z_0; these parameters were then held constant for the remainder of the data at that site. Values of z_0 determined in this manner were z_0 = 4.5, 5.2, 3.5, and 14.2 ft for core data from Assawoman #1, Assawoman #2, Metompkin, and Wallops, respectively. The squared correlation coefficient R^2 was 0.87 for this comparison.

The value of c_v = 26.9 ft^2/yr results in initially rapid consolidation rates that exceed those measured for the first three sites that Gayes (1983) studied, Assawoman #1 and #2, and Metompkin. Gayes indicated that the fourth site, Wallops Island, was the least natural of the islands studied, with a seawall fronting the site and infrastructure including roads and buildings on the island. Thus, there is some justification for this site having a different (larger) coefficient of consolidation than the more natural sites due to the artificial loading and unnatural conditions. If the coefficient of consolidation is reduced for the first three sites to c_v = 1.1 ft^2/yr (representative of medium sensitive clays, Holtz and Kovacs, 1981), the comparison between measured and predicted consolidation improves (Fig. 5). Values of z_0 determined in this manner were z_0 = 4.8, 4.7, and 3.5 ft for core data from Assawoman #1, Assawoman #2, and Metompkin, respectively. Wallops Island consolidation was calculated with the previous value of c_v = 26.9 ft^2/yr. The squared correlation coefficient for Figure 5 was R^2 = 0.95.

MODEL APPLICATIONS

Calibration for Louisiana Barrier Islands

Before model runs could be conducted, a representative value for the thickness of compressible sediment, z_0 as shown in Figure 4 and entering in Equations 4 and 6 was estimated. This value was determined through an iterative procedure with the model, using barrier island and forcing conditions similar to those observed at Grand

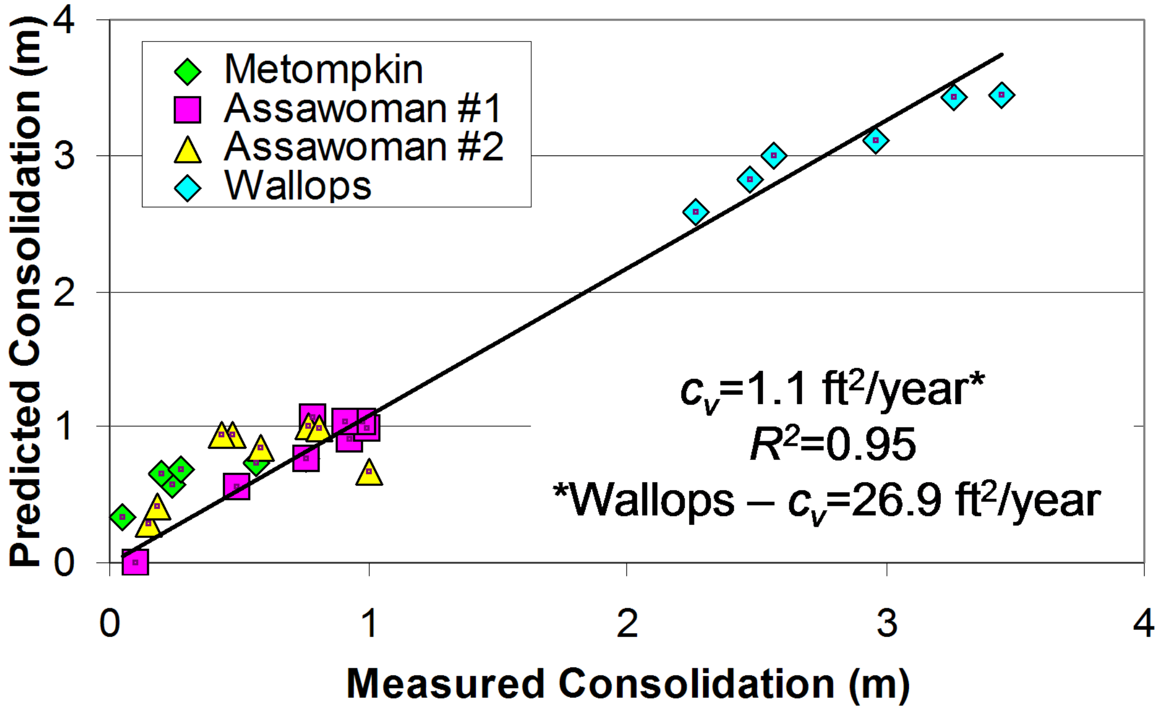

Figure 5. Validation of MCO model with data from Virginia, with coefficient of consolidation equal to 1.1 ft^2/yr (for Assawoman and Metompkin islands) and 26.9 ft^2/yr (for Wallops Island).

Isle, Louisiana. The initial dune height was 9.8 ft, representative of dunes on Grand Isle that have been increased in elevation with beach nourishment (Campbell *et al*., 2005a). The coefficient of consolidation was set to c_v = 31.2 ft^2/yr, representative of silts and clays (Holtz and Kovacs, 1981). Average storm deep water wave height and surge averaged 4.9 ft. Through iteration with the MCO model, a value of z_0 = 15.4 ft was found to reproduce the relative sea-level rise rate that has been observed at Grand Isle over a 50-yr period (0.39 in/yr), if the eustatic sea-level rise rate equal to 0.095 in/yr (Stone and Morgan, 1993) is applied. Implicit in this application is that consolidation has caused the difference between observed and eustatic sea-level rise at Grand Isle. Of course, other factors, such as fluid extraction (oil, gas, water) and natural geologic faulting may contribute to the observed rate of relative sea-level rise.

Large-Scale versus Incremental Restoration

Model applications compared the migration, dune lowering, and consolidation of a barrier island with sediment restoration using a one-time, large infusion of sediment versus a more traditional approach of smaller volumes of sediment placed incrementally through time. Both applications totaled the same volume of introduced sediment; however, the entire volume of the large-scale restoration was placed at the start of the simulation, whereas the incremental volume was set at 10% of the total volume, placed every 10 years, for 100 years. The massive nourishment has the advantage of providing more protection, but it also causes more consolidation, thereby reducing the barrier dune elevation. Which type of placement is best to reduce barrier migration and increase final dune crest elevation?

The simulations were conducted with a cross-section similar to barrier islands in Louisiana: a barrier island with dune height = 4.9 ft and width = 4,900 ft, average storm surge (including astronomical tide) equal to the zeroth-moment deep water wave height = 4.9 ft, and average peak wave period calculated with Equation 1 equal to 5.6 sec. The total volume of sediment placed on the barrier was 1,000 yd^3/ft. For the incremental placement, 10% of this volume (100 yd^3/ft) was placed on the barrier island every 10 years for 100 years. Typical nourishment volume densities in the United States are of the order 100 yd^3/ft (Dean, 2002, p. 23), which is replicated by the first incremental simulation. The simulations were run for 200 years, as shown in Figure 6.

As would be expected, the large-scale restoration simulation had the largest consolidation value, 2.5 ft, as compared to 1.3 ft for the incremental nourishment. However, the large-scale restoration experienced no migration, as compared to 1,380 ft for the incremental nourishment. The large-scale restoration also had the higher final barrier elevation after a 200-yr simulation, 13.5 ft, as compared to the incrementally-placed nourishment, which had a final barrier elevation equal to 3.3 ft. Simulations were conducted for half these quantities (500 yd^3/ft for the large-scale restoration, and 50 yd^3/ft for the incremental nourishment). These simulations had similar responses relative to each other, except the differences were not as pronounced (for the large-scale and incremental nourishments, respectively: final consolidation, 2.0 and 0.6 ft; final migration, 46 and 2,175 ft; and final dune elevation, 8.3 and 2.7 ft). Thus, for the conditions evaluated in this test, a large-scale restoration with beach nourishment decreases barrier migration and results in higher barrier dune elevations than a more traditional, incrementally-placed beach fill project.

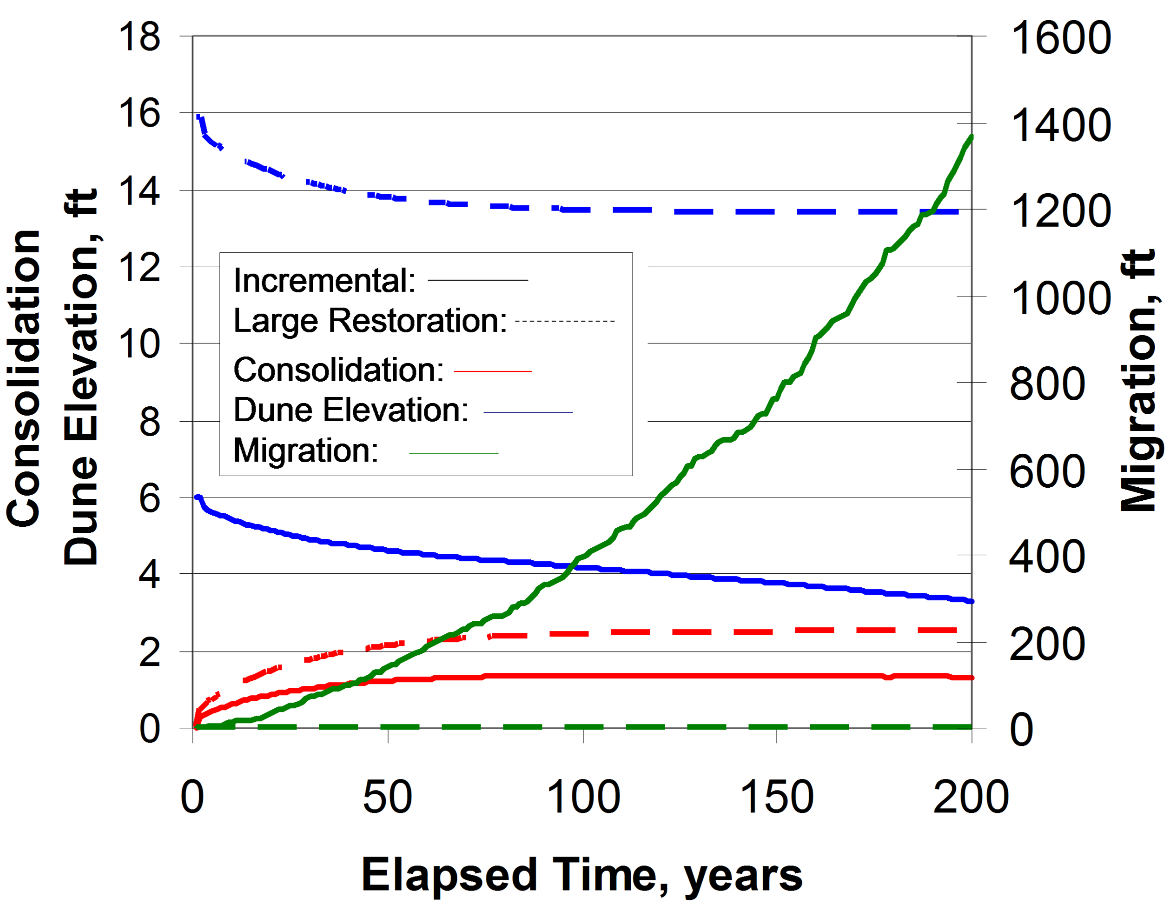

Figure 6. Comparison of large-scale restoration with beach nourishment versus incrementally-placed nourishment.

SUMMARY AND CONCLUSIONS

Late Holocene barrier islands in the northern Gulf of Mexico differ from sandy barrier islands on other coastlines. These islands consist of very fine sand overlying poorly-consolidated, organic-rich, fine silts and clays, and experience a high rate of relative sea-level rise due, in part, to subsidence. Lowering of the barrier island creates an environment in which overwash, breaching, inlet formation, and inlet shoal abandonment are more likely. Washover sediment is lost to the barrier system as wind-generated waves erode the bayshore. No transporting mechanism is operational for returning sediment to the barrier island, unless the barrier island recaptures sediment by migrating on top of a deposit at a later time.

Large-scale restoration of these barrier islands with sediment infused from an external source is being considered as a means of providing storm protection to the sensitive estuarine, bay, wetland, and mainland shores to the lee of barrier islands. Design of large-scale nourishment for these barrier islands must differ from that applied to sandy barrier island systems because of the compressible substrate. Additional loading due to large-scale restoration will increase the magnitude and rate of subsidence. Present beach fill procedure does not take into account the time-dependent consolidation due to loading by placement of sediment on these islands and future maintenance. A newly-developed two-dimensional (cross-shore) mathematical model was applied to investigate the dependence of beach nourishment on barrier island morphologic change within a poorly-consolidated setting. Initial results indicate that, to minimize barrier island migration and maintain dune height, it is advantageous to construct one large nourishment project, rather than smaller projects that are renourished incrementally.

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